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Research on Fire Alarm System

Zhiyu Chen

College of Electronic Science and Technology, Nanjing University of Science and Technology, Nanjing, Jiangsu, 210094, China

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Abstract: In this paper, by coding the data, statistics and screening out the alarm times, false alarm times, non-false alarm times and failure times of each component that can be warned, and the index evaluation model is established by using the analytic hierarchy process. The two first-level indicators, the rate, are used to measure the weight of early warning components to evaluate various types of components, and select reliable fire detector types according to the evaluation scores. In addition, the principal component analysis method is used to screen out the core indicators to remove the influence of redundant indicators, and establish the judgment threshold of the early warning reliability rate. When the threshold is lower than the threshold, it is regarded as a false alarm, so as to monitor the fire alarm situation. Finally, the analytic hierarchy process is used to build a model again, the weights of the newly introduced jurisdiction indicators are redistributed, the fuzzy comprehensive evaluation method is used to evaluate the comprehensive management level of each jurisdiction, and the management scores of the jurisdictions are ranked. Furthermore, the error sensitivity analysis of the evaluation model is carried out.

1. Introduction

Since the 1990s, the industrialization of fire detection and alarm in my country has developed very rapidly [1]. There are more than 100 enterprises engaged in the production of fire detection and alarm products, with an annual output value of several billion yuan. It has become an integral part of my country's high-tech industry. Products have also entered the Chinese market in large numbers. About 2 million fire detectors are newly installed in buildings in my country every year.

Upholding the safety of people's lives and property above everything else, the industrialization of fire detection and alarm in my country has developed rapidly in recent years [2]. Fire detection and alarm have become an important part of my country's high-tech industry, and foreign products have also flooded into the Chinese market. The main function of the fire detector is to capture specific fire analog signals, convert them into electrical signals and transmit them to the terminal server for alarming. Therefore, the sensitivity of the detector determines the sensitivity of the response to the fire characteristics [3]. Higher sensitivity will reduce the reliability of the alarm, while higher reliability requires sacrificing sensitivity. Therefore, searching for the parameter balance of sensitivity and reliability of fire detectors has become a key parameter for evaluating detectors.

2. Analytic hierarchy process

Analytic hierarchy process (AHP) is to decompose the decision-making problem into different hierarchical structures in the order of the overall objective, sub-objectives, evaluation criteria and specific investment plans, and then use the method of solving the eigenvectors of the judgment matrix to obtain the priority weight of an element to an element at the previous level, and the final weighted sum method is to recursively merge the final weight of each alternative to the total goal, and the one with the largest final weight is the optimal plan.

The decision-making problem is decomposed into three levels. The top level is the target level M, which is to evaluate the fire alarm system in the city [4], the bottom level is the program level, that is, the evaluation targets are each alarm system and the city's 18 jurisdictions; the middle level is the criterion. Layer C includes four indicators: the number of alarms C1, the number of failures C2, the reliability rate C3 and the jurisdiction C4, as shown in Fig. 1.

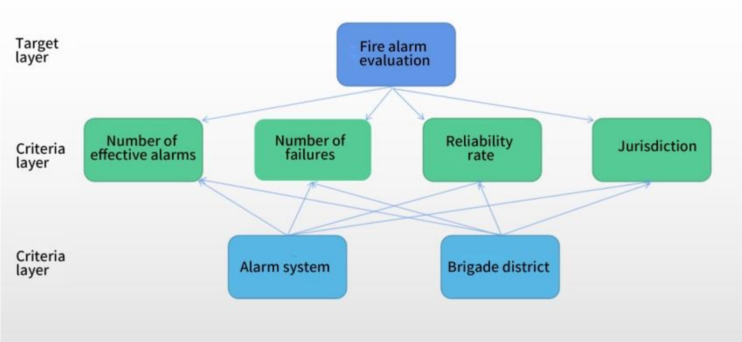

Figure 1 AHP block diagram

AHP is mainly completed through the following two core steps:

Step 1: Constructing the judgment matrix

Using AHP to analyze problems requires constructing a judgment matrix first. Supposing now that we want to compare the influence of n factors $X = \{x_{1,} \dots, x_n\}$on a certain factor Z, we need to use the psychological judgment model established by Saaty et al. Factors are compared pairwise. That is, take two factors x_i and x_j each time, and use a_{ij} to represent the ratio of the influence of x_i and x_j on z. At this time, we can construct the matrix A as the judgment matrix between Z-X:

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} \quad (1)$$

Step 2: Sorting and consistency check

The judgment matrix A corresponds to the eigenvector W of the eigenvalue λ. Whether the eigenvector W can be used as a weight vector needs to be checked for consistency. If the consistency requirement can be met, the eigenvector corresponding to the non-zero eigenvalue can be normalized, if the consistency requirement cannot be met, within a certain allowable range, the normalized eigenvector corresponding to the largest eigenvalue can be used as the weight vector. For the determination of the allowable range, it is necessary to define an index that can evaluate the inconsistency of the judgment matrix. Here, $CI = \frac{\lambda - n}{n-1}$ is used to calculate. In order to measure the size of CI, a random consistency index RI is introduced. Psychologists give random consistency index RI according to experiments.

Constructing the judgment matrix and compare the indicators in the criterion layer pairwise to obtain a paired comparison matrix table, as shown in table 1.

Table 1 Comparison matrix table

M	C1	C2	C3
C1	1.0	1.4	1.7
C2	0.7	1.0	3.5
C3	0.6	0.3	1.0

Finding the eigenvalue as 3, the weight vector $w = (0.6,0.2,0.1)$, which is calculated by the formula $CR = \frac{CI}{RI}$, the consistency test is qualified. After processing and screening the attachment data, five main alarm components and their performance are obtained after one-hot encoding and statistics. The results are shown in table 2.

Table 2 Statistics information

Part name	Number of alarms	Number of fires	Reliability	Number of failures
Number of failures	11225	109	0.97%	568185
Manual alarm button	6566	60	0.91%	209045
Point temperature detector	6881	37	0.54%	231098
Linear beam smoke detector	1927	3	0.16%	2234
Point type smoke detector	230357	188	0.08%	1389358

Each component was scored, and the results obtained are shown in table 3.

Table 3 Score information for each component

	Index weight	Smart photoelectric probe	Manual alarm button	Point temperature detector	Linear beam smoke detector	Point type smoke detector
Reliability rate	0.72%	0.97%	0.91%	0.54%	0.16%	0.08%
Reliability rate	0.28	568185	209045	231098	2234	1389358

The final score radar chart of each component is calculated by scoring each component, as shown in Fig. 2.

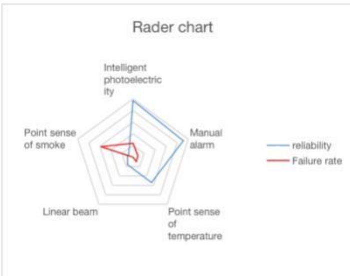

Figure 2 Radar chart of each component score

As can be seen from Fig. 2, among the five components, the manual alarm button and the intelligent photoelectric probe have higher scores, and the point-type smoke detection has the highest failure rate. It is concluded that the reliability of the manual alarm button and the intelligent photoelectric probe is relatively high when alarming the fire [5], the reliability of the point-type smoke alarm probe is low, and the failure rate is high, so the manual alarm button and the intelligent photoelectric probe can be selected.

3. Intelligent research and judgment model

According to the implemented method for judging the threshold value of the alarm device, the alarm threshold values of the five alarm components are calculated, and the results are shown in table 3.

Table 3 Threshold setting table for each component

Alarm parts	Alarm threshold setting
Manual alarm button	0.142
Smart photoelectric probe	0.181
Linear beam smoke detector	0.023
Point temperature detector	0.214
Point type smoke detector	0.075

Constituting the sample matrix:

$$\mathrm{x} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{16} \\ x_{21} & x_{22} & \cdots & x_{26} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{n6} \end{bmatrix} = (x_1, x_2, \dots, x_4) \tag{2}$$

Normalizing the matrix, calculating the mean by column $\overline{x_j} = \frac{1}{n}\sum_{i=1}^{n} x_{ij}$ and standard deviation $S_j = \frac{\sqrt{\sum_{i=1}^{n}(x_{ij}-\overline{x_j})^2}}{n-1}$the standardized data $X_{ij} = \frac{x_{ij}-\overline{x_j}}{S_j}$ is calculated, and the original sample matrix is standardized into:

$$\mathrm{X} = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{16} \\ X_{21} & X_{22} & \cdots & X_{26} \\ \vdots & \vdots & \ddots & \vdots \\ X_{61} & X_{62} & \cdots & X_{66} \end{bmatrix} = (X_1, X_2, \dots, X_6) \tag{3}$$

Computing the covariance matrix for standardized samples:

$$\mathrm{R} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{16} \\ r_{21} & r_{22} & \cdots & r_{26} \\ \vdots & \vdots & \ddots & \vdots \\ r_{11} & r_{12} & \cdots & r_{16} \end{bmatrix} \tag{4}$$

After standardizing each alarm component, calculate the contribution rate $\mathrm{C} = \frac{\lambda_i}{\sum_{k=1}^{p} \lambda_k}$ $(i = 1,2,\dots,p$, and the cumulative contribution rate. Fuzzy comprehensive evaluation of each alarm component.

The results of the alarm authenticity of the six jurisdictions are shown in table 4, and the alarm reliability brigade occupies the ranking, as shown in Fig. 3.

Table 4 Alarm reliability results of each team's jurisdiction

Fire brigade	Reliability rate	Fire brigade	Reliability rate
Fire brigade A	2.31%	Fire brigade I	0.53%
Fire brigade B	9.12%	Fire brigade J	0.66%
Fire brigade C	1.11%	Fire brigade L	0.77%
Fire brigade D	2.13%	Fire brigade M	0.32%
Fire brigade E	1.17%	Fire brigade N	0.41%
Fire brigade F	1.45%	Fire brigade P	1.54%
Fire brigade G	0.83%	Fire brigade Q	4.33%
Fire brigade H	0.62%	Fire brigade I	0.55%

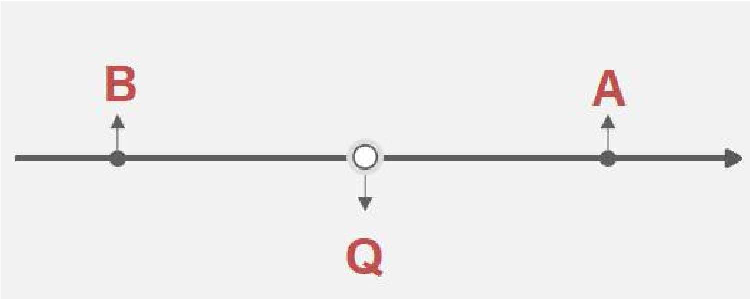

Figure 3 The ranking of the alarm reliability brigade

It can be seen from Fig. 3 that B, Q, and A brigades occupy the top three in the alarm reliability of all brigades respectively.

The discrete data is presented as a sequence, and the initial data is generally objective empirical data or observation data. Let the initial data array be $x_{(0)}(k), (k = 1,2, \ldots n)$.

Adding the data in the original sequence successively, and replace the original number with the obtained sum to generate a new number.

Let the initial data sequence be (2-1) namely: $x_{(0)}(k) = \{x_{(0)}(k)|k = 1,2, . . n\}$.

Therefore, the data sequence accumulated for m times is defined as follows:

$$X_m(k) = \{\sum_{i=1}^{k} x_{(m-1)}(i)|k = 1,2,3, \ldots, n\} \tag{5}$$

Assuming that the operation symbol of the reduction operation is α, the expression of the new sequence generated after the cumulative reduction is:

$$\alpha^{(m)}(X(k)) = \alpha^{(m-1)}(X(k)) - \alpha^{(m-1)}(X(k-1)) \tag{6}$$

Table 5 shows the calculation of the scores of the three brigades in terms of fire frequency, component failure rate, and component reliability.

Table 5 Calculation result table

	Fire frequency	Failure rate	Reliability
Fire brigade M	0.017	0.211	0.315
Fire brigade N	0.033	0.149	0.420
Fire brigade I	0.023	0.328	0.537

It can be seen from table 5 that the reliability of the components of the M brigade is low, and it is necessary to consider replacing the more reliable fire alarm components such as manual alarm buttons and intelligent photoelectric probes for alarming; The processing and management ability is improved through training; the parts failure rate of the I brigade is relatively high, and it is necessary to consider replacing parts with a low failure rate.

4. Error sensitivity analysis

Calculating $\hat{X}^{(1)}(i)$, according to the prediction model, accumulating $\hat{X}^{(1)}(i)$ to generate $\hat{X}^{(0)}(i)$, and then calculating the absolute error sequence and relative error sequence of the original sequence X(0)(i) and $\hat{X}^{(0)}(i)$:

$$\Delta^{(0)}(i) = \left|X^{(0)}(i) - \hat{X}^{(0)}(i)\right| \qquad i = 1,2, \ldots, n \tag{7}$$

Picking a reference number sequence:

$$X_0 = \{X_0(k)|k = 1,2, \ldots, n\} = (X_0(1), X_0(2), \ldots, X_0(n)) \tag{8}$$

where k is the time. Supposing there are m comparison sequences:

$$X_i = \{X_0(k)|k = 1,2, \ldots, n\} = \left(X_i(1), X_i(2), \ldots, X_i(n)\right) i = 1,2, \ldots, m \quad (9)$$

So $\xi_i(k) = \frac{\min\limits_i \min\limits_k |X_0(k)-X_i(k)|+\rho \quad \max\limits_i \max\limits_k |X_0(k)-X_i(k)|}{|X_0(k)-X_i(k)|+\rho \quad \max\limits_i \max\limits_k |X_0(k)-X_i(k)|}$.

where $\xi_i(k)$ is the correlation coefficient between the comparison sequence X_i and the reference sequence X_0 at time k, where ρ∈[0,1] is the resolution coefficient, generally taking ρ=0.5. where $\min\limits_i \min\limits_k |X_0(k) - X_i(k)|$ and $\max\limits_i \max\limits_k |X_0(k) - X_i(k)|$ are the two-level minimum difference and the two-level maximum difference, respectively. It is easy to see that the larger the ρ, the greater the resolution; the smaller the ρ, the smaller the resolution.

$r_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k)$ is the correlation degree of the sequence X_i to the reference sequence X_0. It can be seen from the formula that the correlation degree is to concentrate the correlation coefficients of each moment into an average value, that is, to centrally deal with the information that is too scattered. Calculating the correlation coefficient with the original sequence $\hat{X}^{(0)}(i)$ according to the above-mentioned correlation degree calculation method, and then calculate the correlation degree. According to experience, when ρ=0.5, when the correlation degree is greater than 0.6, it is full meaning.

The standard deviation of the original series is:

$$S_1 = \sqrt{\frac{\sum\left[X^{(0)}(i) - \bar{X}^{(0)}\right]^2}{n-1}} \quad (10)$$

Computing the standard deviation of the absolute error series:

$$S_2 = \sqrt{\frac{\sum\left[\Delta^{(0)}(i) - \bar{\Delta}^{(0)}\right]^2}{n-1}} \quad (11)$$

Calculating the variance ratio:

$$\mathrm{C} = \frac{S_2}{S_1} \quad (12)$$

Computing the small error probability:

$$\mathrm{P} = \mathrm{p}\left\{\left|\Delta^{(0)}(i) - \bar{\Delta}^{(0)}\right| < 0.6745 S_1\right\} \quad (13)$$

The inspection standard table is shown in table 6.

Table 6 Inspection standard table

C	Inspection standard
<0.35	Fail
<0.5	Medium
<0.85	Good
>0.95	Very good

Calculating the above error with VARPA and other functions in EXCEL: S1= 1.7199e+04, S2=1.7270e+04, and C = 0.9959

The estimated values and statistics of the obtained parameters are shown in table 7.

Table 7 Parameter estimation table

Estimation value	T value	P value
θ = 0.78989	0.988914366	0.333457493

The mean square error is 240614.847, the absolute error is 443.7093059, and the complex correlation coefficient is 0.999593415. From the calculation results, all passed the significance test. The error of numerical fitting is relatively small. It shows that the fitting effect is good, the autocorrelation coefficient obtained by the fitting error is shown in Fig. 4, and the partial correlation coefficient is shown in Fig.5.

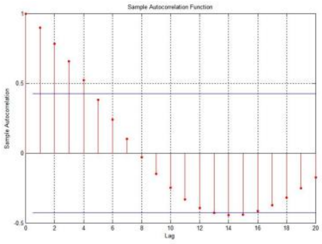

Figure 4 Autocorrelation coefficient plot

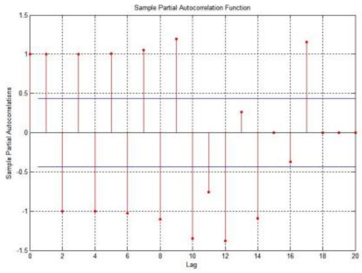

Figure 5 Partial correlation coefficient plot

The cross-correlation images and absolute error heatmaps are plotted in the MATLAB toolbox as shown in Fig. 6 and Fig. 7.

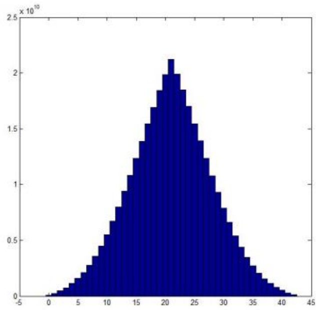

Figure 6 Cross-correlation plot

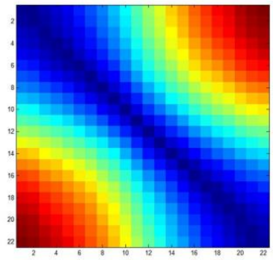

Figure 7 Absolute error heatmap

The function of the evaluation model can be seen through the analysis of the error sensitivity. Compared with most earlier models, the data at this stage is more comprehensive and can explain the problem better. The possible threshold limit setting is used to support the intelligent research and judgment of the fire alarm system.

5. Conclusion

AHP has the advantages of being systematic and concise. The principal component factor analysis method can remove the interference of redundant variables on the target factors and screen out the key index factors. Fuzzy evaluation can process fuzzy evaluation objects by digital means, and quantify and comprehensively evaluate indicators. The principal component factor analysis method is weak in judging the correlation between the influencing index and the target layer factor. Subsequent research can further analyze the correlation degree between the target factor and the influencing index factor through the ADF test and the gray correlation method.

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